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ACOUSTICAL COMPUTER SIMULATIONS OF THE ANCIENT ROMAN THEATRES

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The objective of this work (under WP5 of the ERATO project) has been to create and analyse acoustical models of the selected theatres and odea by means of a computer simulation programme (named ODEON). Models have been created of the monuments both as originally built (to the extent that this is known), in their present state (as ruins), and with the temporary stages and scenery often applied when these spaces are used as performance venues today. Hereby, it has become possible to quantify the acoustical properties of the ancient theatres and odea in each condition leading to valuable information regarding the acoustical consequences and degree of authenticity of permanent restorations and temporary amendments. Moreover, based on recorded samples of authentic style music/speech (resulting from WPs 3 and 4), the simulations also have produced audible sound demonstrations of virtual performances with a high degree of acoustic realism. These sound files have been integrated with the visual restorations (WP 6) to form the audio in 3D virtual realizations of performances in the selected venues (WP7). The simulations of the acoustic conditions have been calibrated through comparison of the calculated results from the monuments in their present state with the actually measured acoustic data (from WP4). Also comparisons with the scale model studies contained in WP4 have ensured a high degree of accuracy in both modelling techniques supporting a deeper insight into the acoustics of ancient theatres and odea in general.

1 INTRODUCTION

One of the objectives of this project is to study the acoustical properties of ancient theatres and to discuss their ‘excellent’ acoustics as they generally are described. This task has earlier been carried out by different authors, most notably by F. Canac [1], who proposed canonical formulas derived from geometrical observations. With the advantage of modern computers and room acoustic simulation software, today we can get further information about the theatres by modelling them in a virtual environment.

Therefore it is within the scope of the ERATO project to provide a virtual reconstruction of the acoustics in the Roman period, both in its large open-air theatres and in smaller roofed theatres (Odea). This makes it possible for the first time to listen to these historical buildings as they sounded in the past.

In total, five theatres from the Roman era have been recreated in the ERATO project, where three are open-air theatres and two are indoor odea.

2 ACOUSTICAL COMPUTER MODELS

The acoustical models of the theatres in the ERATO project were made using the following software packages in the different stages: ODEON Modeling Language, IntelliCAD and 3DStudioMax.

The degree of detail needed in the construction of the models and the influence of the seating area on the acoustics was determined in previous studies [2] and the models have previously been compared to measurements [3].

The absorption and scattering properties of the materials were indirectly estimated by comparing simulations of the present state models with these in-situ measurements and with the available literature.

Models of the theatres were first created based on the remaining sites at present, and then the reconstruction was added to reproduce the theatres as originally built (to the extent that this is known). The acoustical simulations of these models were carried out with the use of the ODEON 7 acoustical simulation software.

In order to understand the acoustical importance of some chosen geometrical parts of the theatre, these were removed one at the time from the reconstructed models. The results of these modifications became both visible through the acoustical parameters but also audible through the auralised sound signals which were calculated [4].

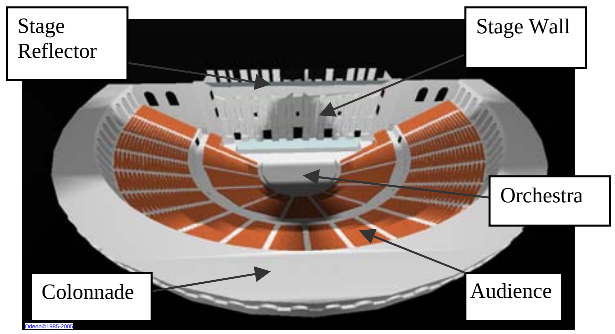

Figure 1: Acoustical model of the Aspendos open-air theatre in its Roman era with indication of geometries of acoustical interest

2.1 Aspendos open-air Roman theatre, Antalya, Turkey

The Aspendos Roman theatre was chosen since it is one of the best preserved theatres in the world and it strictly follows the recomendations of the roman architect Vitruvius [5]. The reconstruction of this theatre which could have an audience of up to 7000 people did not imply too many assumptions since its present state is close to the original building.

In Figure 1 the reconstructed model of the Aspendos theatre counting 6613 surfaces is shown, with indication of the geometrical parts that have an acoustical interest. First the stage wall was chosen as an interesting geometry, having sound diffusing geometries as columns, niches and architectural relief decoration. The effect of the diffusing elements and the removal of this wall were studied.

At a height of 25m over the stage there was a wooden tilted roof which might have worked as a stage reflector. The semicircular orchestra was separating the stage and the seating area and could have the effect of a reflecting surface when not covered by people. On the upper part of the theatre behind the last rows of seats there was a colonnade similar to an arcade where the audience were able to rest in the shade and enjoy light breezes from the outer windows. All these parts of the theatre have been thoroughly studied.

2.2 Aphrodisias Roman Odeon, Antalya, Turkey

The Aphrodisias Roman Odeon had a volume of 20190 m3 and a seating capacity of approximately 1700 people. The computer models of this odeon, shown on Figure 2, were based on the reconstructions suggested by Izenour [6] and the number of surfaces used was 5058.

Changes on the shown parts were studied in the simulations. The roof was made of a timber structure hidden and decorated with a coffered ceiling. It was tested how the coffered structure influenced the acoustics by replacing it with a flat roof.

The windows were usually open but had also wooden shutters that could be used depending on the weather conditions. The effect of closing the windows was studied.

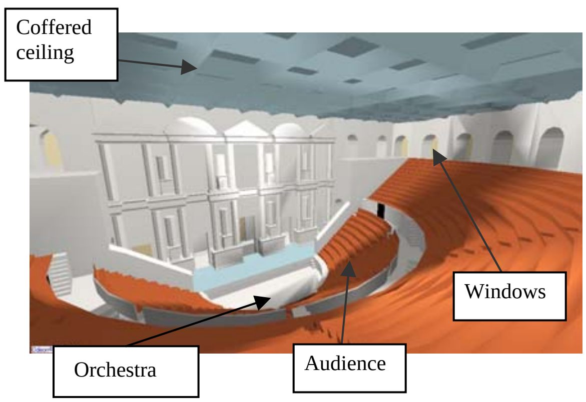

Figure 2: Acoustical model of the Aphrodisias odeon in its Roman era with indication of geometries of acoustical interest

3 SIMULATION RESULTS

The simulations in the Aspendos open-air theatre were made with 500000 rays and in the Aphrodisias Odeon with 100000 rays. The greater amount of rays in the open-air theatre was needed due to the simulated "open-air" effect (a totally absorptive roof was introduced representing one third of the total surface area).

The theatre models have been simulated as fully occupied in order to be able to make comparisons with existing concert halls. Contrary to today's halls, the acoustics of the Roman theatres differ dramatically when empty and full as the seats are not upholstered.

In all the simulations the sound sources are omni directional and they are placed on the acting stage. There are 15 receivers distributed in two radial lines diverging from the orchestra as shown in the theatre model of Aspendos in Figure 3.

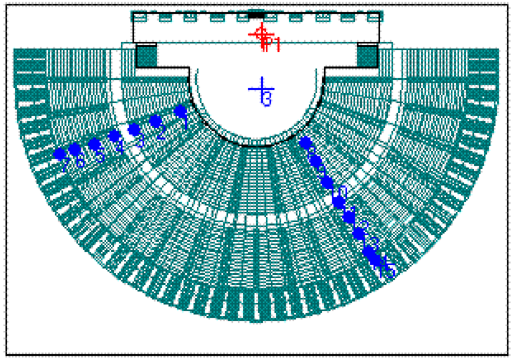

Figure 3. Sound sources and receivers in the Aspendos theatre.

In the Aphrodisias Odeon the placement of sources/receivers follow the same distribution. As mentioned before, the parts judged to be of acoustical interest were subtracted one at the time from the reconstructed model. The reconstructed model is hereby mentioned in this paper as the Reference model.

3.1 Aspendos Open-Air Theatre

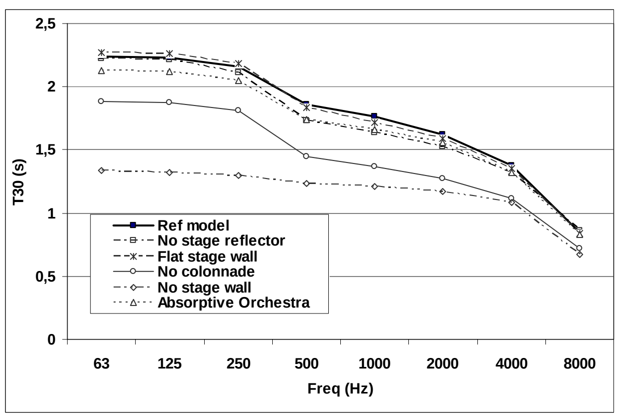

Figure 4. Simulated reverberation time T_{30} as a function of 1/1 octave frequency bands

In the acoustical simulations of the reconstructed Aspendos Roman theatre, the reverberation time at mid-frequencies is shown in Figure 4 to be of 1,8 s. In all the configurations the simulations show that the reverberation time is around 0,5 s higher at low than at mid-frequencies. The tendency towards a lower reverberation time at higher frequencies for all configurations is mainly due to air and audience absorption. For being an open building it should be noticed that there is a considerable reverberation in the room.

The stage wall and the colonnade seem to be the largest contributors to the reverberation time. By removal of these parts the reverberation time is seen to fall substantially, particularly at lower frequencies.

Table 1. Simulated acoustical parameters averaged over the 500-1000 Hz 1/1 octave frequency bands for the Aspendos Roman theatre with audience and averaged over 15 receiver positions in different configurations.

Theatre Configuration	Acoustical Parameters				
	T_{30} (s)	G (dB)	C_{80} (dB)	STI	DL2 (dB)
Reference model	1,81	-4,02	5,43	0,63	4,80
Flat Stage Wall	1,78	-4,81	4,82	0,61	5,31
No Stage Wall	1,22	-8,11	10,57	0,81	6,82
No Stage Reflector	1,69	-4,87	6,87	0,68	4,83
No Colonnade	1,41	-4,50	6,67	0,66	5,79
Absorbing Orchestra	1,70	-4,95	5,26	0,63	4,03

In table 1 are shown the overall differences of the modified theatre models compared to the reconstructed reference model at mid-frequencies.

By using a flat stage wall without diffusing geometries it is seen that the overall strength level G is reduced and the DL2 rate is increased. By removing the geometries of the stage wall the sound field in the theatre becomes less diffuse and more dominated by specular reflections. These dissipate quicker through the open roof resulting in a lower sound level in most of the seats.

By removing the stage wall it is seen that the reverberation time decreases dramatically resulting in a substantial increase of clarity and STI but in detriment of the strength level.

Without stage wall few early reflections from a vertical surface reach the receivers. The sound propagates in a similar way to free field conditions and this is exemplified by the level decay per distance doubling which is about 6 dB.

3.2 Aphrodisias Odeon

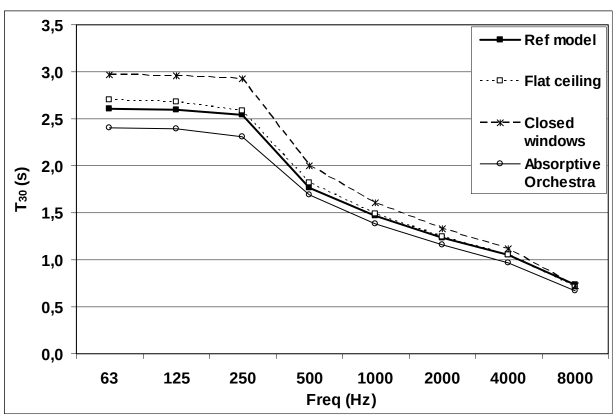

Figure 5. Simulated reverberation time T_{30} as a function of 1/1 octave frequency bands averaged over 15 receiver positions in different configurations.

In Figure 5 the reverberation time as a function of frequency in the different configurations of Aphrodisias is shown. The reconstructed model includes a coffered ceiling and open windows. All the simulations in this odeon show a similar tendency in frequency, a long and constant reverberation time at lower frequencies and an abrupt fall toward the mid-frequencies. At higher frequencies the audience and air absorption make the differences between the curves smaller. At mid- and high frequencies the reverberation time of the reconstructed model suggests that it is a room suited for musical performances.

Table 2. Simulated acoustical parameters averaged over the 500-1000 Hz 1/1 octave frequency bands for the Aphrodisias Roman odeon with audience and averaged over 15 receiver positions in different configurations.

Theatre Configuration	Acoustical Parameters				
	T_{30} (s)	G (dB)	C_{80} (dB)	STI	DL2 (dB)
Reference model	1,61	5,61	2,22	0,54	3,47
Flat Ceiling	1,66	4,84	2,49	0,55	4,08
Closed Windows	1,80	6,10	1,46	0,52	2,89
Absorbing Orchestra	1,54	5,07	2,97	0,57	3,32

By closing the windows with wooden shutters a considerably longer reverberation time is obtained. It is almost comparable to the reverberation time of modern concert halls of similar volume. Linked to the higher reverberation time are the overall higher strength and lower clarity. Although in general the clarity seems to be good in any of the configurations.

Omission of the reflections coming from the orchestra does not cause dramatic changes but gives a higher clarity. But in general it can be said that reflections from the stage wall and the roof are more important than the reflections from the orchestra.

The STI seems to be good in all the configurations making this room a suitable place for both music and spoken word.

4 SUMMARY

The acoustics of typical performance venues in the Roman era have been studied in detail by using computer simulations. In the computer models certain parts of the theatre have been changed or removed and the acoustical consequences of these alterations have been studied.

The computer simulations show that at least two modifications introduced by the Romans in the open-air theatres had a large influence on the acoustics. Firstly the extension of the stage wall in its width and height which meant a connection with the seating area into a single structure, and secondly the colonnade in the upper part of the theatre which provided a retreat area with shade for the spectators.

These two geometrical modifications of the theatre seem to increase the overall reverberation time with half a second each, amplifying the overall strength level with up to +4dB. This has to be seen as a significant improvement in this type of theatres where large distances between stage and audience implied very low levels (almost inaudible in the upper rows). Furthermore, the level difference between seats near and far from the stage is reduced with the introduction of these geometries.

In the case of the odea the simulations show that these highly reflective rooms (marble surfaces), have similar acoustical properties to modern concert halls when the windows are closed, even though the only absorption is provided by the audience.

In order to answer the question addressed in the main title in a more intuitive way, auralized sound examples of the theatres can be heard at the ERATO website [4] as well as the refered papers can be found.

5 ACKNOWLEDGEMENT

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